Quantification of Mitral Valve Anatomy by Three-Dimensional Transesophageal Echocardiography in Mitral Valve Prolapse Predicts Surgical Anatomy and the Complexity of Mitral Valve Repair

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Background: Three-dimensional (3D) transesophageal echocardiography (TEE) is more accurate than two-dimensional (2D) TEE in the qualitative assessment of mitral valve (MV) prolapse (MVP). However, the accuracy of 3D TEE in quantifying MV anatomy is less well studied, and its clinical relevance for MV repair is unknown.

Methods: The number of prolapsed segments, leaflet heights, and annular dimensions were assessed using 2D and 3D TEE and compared with surgical measurements in 50 patients (mean age, 61 ± 11 years) who underwent MV repair for mainly advanced MVP.

Results: Three-dimensional TEE was more accurate (92%–100%) than 2D TEE (80%–96%) in identifying prolapsed segments. Three-dimensional TEE and intraoperative measurements of leaflet height did not differ significantly, while 2D TEE significantly overestimated the height of the posterior segment P1 and the anterior segment A2. Three-dimensional TEE quantitative MV measurements were related to surgical technique: patients with more complex MVP (one vs two to four vs five or more prolapsed segments) showed progressive enlargement of annular anteroposterior (31 ± 5 vs 34 ± 4 vs 37 ± 6 mm, respectively, $P = .02$) and commissural diameters (40 ± 6 vs 44 ± 5 vs 50 ± 10 mm, respectively, $P = .04$) and needed increasingly complex MV repair with larger annuloplasty bands (60 ± 13 vs 67 ± 9 vs 72 ± 10 mm, $P = .02$) and more neochordae (7 ± 3 vs 12 ± 5 vs 26 ± 6, $P < .01$).

Conclusions: Measurements of MV anatomy on 3D TEE are accurate compared with surgical measurements. Quantitative MV characteristics, as assessed by 3D TEE, determined the complexity of MV repair. (J Am Soc Echocardiogr 2012;25:758-65.)

Keywords: Three-dimensional transesophageal echocardiography, Mitral valve prolapse, Mitral valve repair, Anatomy

Surgical mitral valve (MV) repair provides excellent long-term results in patients with severe mitral regurgitation (MR) due to MV prolapse (MVP).[1,2] Current American College of Cardiology and American Heart Association guidelines advocate MV repair in asymptomatic patients with severe MR and normal left ventricular systolic function if the likelihood of successful repair exceeds 90%.[3] Successful MV repair is related mainly to surgical expertise and MV anatomy.[4,5] Anatomic predictors of lower likelihood of repair are involvement of the anterior leaflet, bileaflet involvement, posterior leaflet height, and the extent of mitral annular disease.[6-9]

Transesophageal echocardiography (TEE) is considered the standard of care for the assessment of MV anatomy[10] and is critical for the stratification of patients with MVP, because it determines both the choice of the surgeon as well as the timing of surgery.[11] Real-time three-dimensional (3D) TEE is more accurate than two-dimensional (2D) TEE in identifying prolapse of single MV segments[12-14] and in patients with advanced MVP.[15-17] Three-dimensional transesophageal echocardiographic quantitative measurements of annular dimensions, billowing volume, and height have been studied in the perioperative setting.[18-20] Although all these studies were performed in comparison with qualitative surgical findings, only very few studies have tested the accuracy of 3D TEE in quantifying MV anatomy compared with direct

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Abbreviations
BD = Barlow's disease
FED = Fibroelastic deficiency
MR = Mitral regurgitation
MV = Mitral valve
MVP = Mitral valve prolapse
TEE = Transesophageal echocardiography
3D = Three-dimensional
2D = Two-dimensional

surgical measurements.[19,21] The accuracy of 3D TEE in measuring leaflet height, and the clinical relevance of quantitative MV assessment for MV repair using 3D TEE, are unknown.

In this study, we compared the accuracy of 2D and 3D TEE in quantifying MVP. In particular, we tested the accuracy of 2D and 3D TEE in measuring leaflet height and annular diameters against detailed surgical measurements. Furthermore, we studied whether qualitative and quantitative MV assessment on 3D TEE correlated with the surgical technique.

METHODS

Study Population

From October 2009 to November 2010, we prospectively enrolled 50 consecutive patients with severe MR due to MVP who underwent elective surgical MV repair at Toronto General Hospital (Toronto, ON, Canada). For patients without previous TEE ($n = 17$), study TEE was performed at our echocardiography laboratory. For patients with preoperative TEE performed at external institutions ($n = 33$), TEE was performed in the operating room. All patients underwent postoperative 2D transthoracic echocardiography before hospital discharge to assess for residual MR. The study was approved by the Toronto General Hospital research ethics committee. All patients gave written informed consent.

TEE

TEE was performed using a Philips iE33 platform and X7-2t real-time 3D transesophageal echocardiographic probes (Philips Medical Systems, Andover, MA). Experienced cardiologists or cardiac anesthetists followed a specific MV protocol[8] as part of a comprehensive transesophageal echocardiographic examination. Two 3D imaging modalities were used: 3D zoom mode ("live" acquisition over two heartbeats) and full-volume mode (four to seven stitched heartbeats), as previously described.[22]

Qualitative and Quantitative Image Analysis on 2D TEE

Two experienced echocardiographers (S.J., C.G.) blinded to the intraoperative findings analyzed the transesophageal echocardiographic studies several weeks after the operation. We used the eight-segment Carpentier nomenclature (Figure 1) to localize prolapsed segments.[23] Prolapse was defined as end-systolic displacement of the body of the MV leaflet ≥2 mm above the annular plane in either the commissural or long-axis view at end-systole.[24] A leaflet was considered flail when the leaflet edge was pointing retrograde into the left atrium at end-systole, whether or not a ruptured chord was seen.[25] Calcification of the mitral annulus had thick, highly echogenic annular deposits with distal shadowing. Leaflet height and anteroposterior and intercommissural annular diameters were measured in end-systole (Figures 2A–2C).

Qualitative and Quantitative Image Analysis on 3D TEE

The 3D transesophageal echocardiographic loops were analyzed by a single observer blinded to the results of 2D TEE and the intraoperative findings (P.B.). Qualitative MV assessment (Figure 2D) involved our systematic approach showing the MV in standardized views at four different angles ("angled views").[26] Prolapse was assessed in end-systole and was defined as any movement of the leaflet body above the adjacent annulus. Flail was defined as described for the 2D images. Ruptured chordae were defined as independently mobile structures attached to the edge of a flail segment. Annular calcification was defined as a bright mass attached to the annulus independent of the adjacent leaflet. Quantitative MV assessment (Figure 2E) was performed offline, using MV quantification software (QLab version 7.1; Philips Medical Systems).[18] The 3D intertrigonal distance was measured according to Suri *et al.*[21]

Intraoperative Findings and Surgical Measurements

All patients were operated by a single surgeon (T.E.D.). Fibroelastic deficiency (FED) was defined as the presence of thin leaflets with single-segment prolapse and ruptured chord(s). Barlow's disease (BD) was defined as prolapse of all segments with bulky, billowing leaflets.[27] Between FED and BD, there is a wide spectrum of MV disease.[28] To simplify this continuous disease spectrum, we divided our study population into groups with simple and advanced MVP.[29] Simple MVP was considered to be prolapse of one segment only. Advanced MVP was defined as two or more prolapsed segments combined with the presence of at least one of the following findings: myxomatous changes (as visualized by the surgeon), excessive leaflet tissue, or relevant annular calcification.

A segment was considered to be prolapsed if the body of the segment fell behind the anterolateral commissure. In cases in which all segments prolapsed, the level of the annulus was used for reference. Annular calcification was identified visually and confirmed by detaching the leaflet and removing the calcium block during repair. A leaflet was defined as flail if there was a ruptured chord or if the chords were largely elongated during inspection. Leaflet height and the intertrigonal distance were measured using a caliper or a long Kelly clamp and a ruler in case of suboptimal exposure (Figures 2F and 2G). The intertrigonal distance was considered the space between the right and left fibrous tissue trigone seen intraoperatively at the base of the anterior MV leaflet and adjacent to the MV commissures. The diameter of the mitral annulus was not measured, because the heart was flaccid due to cardioplegic arrest. The surgeon was aware of the qualitative 2D transesophageal echocardiographic findings on preoperative studies because they were part of the referral data on patients, and he was able to review 2D transesophageal echocardiographic images obtained perioperatively. However, the surgeon was blinded to the qualitative and quantitative 3D transesophageal echocardiographic MV assessment performed offline using the MV quantification software.

Analysis of Different Subgroups of Patients

To determine whether findings on 3D TEE correlated with the type of surgery performed, we divided the study population according to the number of prolapsed segments in three subgroups: simple MVP (one segment involved) and advanced MVP with two subgroups (two to four segments vs five or more segments involved). We compared findings on 3D TEE and the type of surgery performed among the subgroups, and we correlated the degree of disease with the extent of surgery.

Reproducibility of Measurements

The interobserver and intraobserver variability of 3D measurements was determined using 10 full-volume data sets analyzed by a second